ISOLATED NEUTRON STARS: AN ASTROPHYSICAL PERSPECTIVE

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Abstract We briefly review selected results in astrophysics of neutron stars (NSs) obtained during the last two years, focusing on isolated radioquiet objects. We discuss in some details population synthesis of close-by isolated NSs, spectra of INSs, detection of spectral features in these sources (including cyclotron features), recent results on velocity distribution of NSs and accretion onto INSs.

Keywords: neutron stars, evolution, accretion, magnetic field, spectral properties

Introduction

Probably neutron stars (NSs) are the most interesting astronomical objects from the physical point of view. They provide a variety of different *extreme* phenomena: magnetic field over the QED limit, supranuclear density, superfluidity, superconductivity, exotic matter states, etc.

There are about $10^8 - 10^9$ NSs in the Galaxy and their local density is about 3×10^{-4} pc^{-3} (see fig. 1). [1] At present only a small fraction (about 2000 sources) of this large population is observed as isolated objects of different nature and as accreting objects or millisecond radio pulsars in binaries. Young NSs can be observed for several million years dissipating their rotational, thermal or/and magnetic energy. Most of old NSs are dim objects without significant internal sources of energy. If a NS looses its strong magnetic field on

[1]Here and below we will not distinguish between NSs, quark stars, hybrid stars etc. unless explicitely stated.

a time scale $< 10^8$–10^9 yrs then it can be resurrected by accretion from the interstellar medium (ISM) or from a binary companion (small number of old NSs can be spin-up by disc accretion and appear as millisecond radio pulsars). However, as we will discuss later on, there is no much hope that a significant number of isolated NSs can be bright accretors, so most of NSs are unobservable.

The main parameters which determine the astrophysical appearance of NSs are:

- Spin period, p
- Magnetic field, B
- Mass, M
- Spatial velocity, v
- Surface temperature, T
- Angle between spin and magnetic axis, α

Parameters of the surrounding medium (interstellar medium or matter from the binary companion) are also important.

Here we will focus on isolated NSs (INSs). At present the following types of these sources are observed:

1. Radio pulsars (PSRs)
2. Anomalous X-ray pulsars (AXPs)
3. Soft gamma repeaters (SGRs)
4. Compact central objects in supernova remnants (CCOs in SNRs)
5. Geminga and geminga-like object(s)
6. The “Magnificent seven” — seven dim ROSAT sources

INSs may lurke within unidentified EGRET and ROSAT sources and, possibly, among dim X-ray sources observed by XMM-Newton and Chandra in globular cluster (see Pfahl, Rappaport 2001) or in the galactic center (see Muno et al. 2003). Except PSRs all others are more or less radioquiet (which, however, does not mean that they are necessarily radio silent).

Astronomy is the only purely observational natural science. All the information we have come through the electromagnetic emission from celestial bodies — no direct experiments are possible (of course except some rare cases in the Solar system). This is why progress in astronomy is necessarily connected with new observational facilities. Astrophysics of NSs is a quickly growing field. New space observatories (especially XMM-Newton and Chandra) give us an opportunity to obtain increadible spatial and spectral resolution in the X-ray band. New radio surveys of PSRs doubled the number of know objects of this type over the last few years. Data from optical and IR telescopes foster new

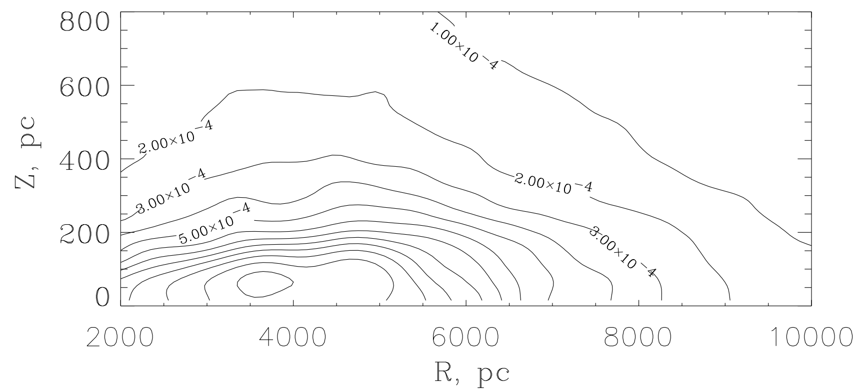

Figure 1. Spatial distribution of NSs in the Galaxy. The data was calculated by a Monte-Carlo simulation. Kick velocity was assumed following Arzoumanian et al. (2002). NSs were born in the thin disk with semithickness 75 pc. No NS born inside $R = 2$ kpc and outside $R = 16$ kpc were taken into account. NS formation rate was assumed to be constant in time and proportional to the square of the ISM density at the birthplace. Results were normalized to have in total 5×10^8 NSs born in the described region. Density contours are shown with a step 0.0001 pc^{-3}. At the solar distance from the center close to the galactic plane the NS density is about $2.8 \cdot 10^{-4}$ pc^{-3}. From Popov et al. (2003a).

discoveries in NS astrophysics. The huge flow of new observational data stimulated theoretical studies. Here we briefly review recent results in astrophysics of NSs which can be of interest for participants of this conference – mainly physicists working on quark stars and related subjects. In the next section we just give a list of them (we do not try to summarize results directly connected to quark stars since they are presented in other contribution in this proceedings). Then in the following sections we comment on some of them in more details, focusing on INSs and paying more attention to the results connected with our own research.

1. What's new

In this section we give a list of new important discoveries in obervational and in theoretical astrophysics of NSs. In the observational part of the list we usually give objects names, determined parameters and reference to the original paper. In the theoretical part we sometimes just name the topic of research and give references to original papers or/and reviews on that topic.

Table 1. Local ($D < 1$ kpc) population of young (age < 4.25 Myrs) isolated neutron stars

Source name	Period s	CR^a cts/s	$\dot{P}$ 10^{-15} s/s	D kpc	Age^b Myrs	Refs
RINSs						
RX J1856.5-3754	—	3.64	—	0.117^e	~ 0.5	[1,2]
RX J0720.4-3125	8.37	1.69	$\sim 30-60$	—	—	[1,3]
RX J1308.6+2127	10.3	0.29	—	—	—	[1.4]
RX J1605.3+3249	—	0.88	—	—	—	[1]
RX J0806.4-4123	11.37	0.38	—	—	—	[1,5]
RX J0420.0-5022	3.45	0.11	—	—	—	[1,11]
RX J2143.7+0654	—	0.18	—	—	—	[6]
Geminga type						
PSR B0633+17	0.237	0.54^d	10.97	0.16^e	0.34	[7]
3EG J1835+5918	—	0.015	—	—	—	[8]
Thermally emitting PSRs						
PSR B0833-45	0.089	3.4^d	124.88	0.294^e	0.01	[7,9,10]
PSR B0656+14	0.385	1.92^d	55.01	0.762^f	0.11	[7,10]
PSR B1055-52	0.197	0.35^d	5.83	$\sim 1^c$	0.54	[7,10]
PSR B1929+10	0.227	0.012^d	1.16	0.33^e	3.1	[7,10]
Other PSRs						
PSR J0056+4756	0.472	—	3.57	0.998^f	2.1	[10]
PSR J0454+5543	0.341	—	2.37	0.793^f	2.3	[10]
PSR J1918+1541	0.371	—	2.54	0.684^f	2.3	[10]
PSR J2048-1616	1.962	—	10.96	0.639^f	2.8	[10]
PSR J1848-1952	4.308	—	23.31	0.956^f	2.9	[10]
PSR J0837+0610	1.274	—	6.8	0.722^f	3.0	[10]
PSR J1908+0734	0.212	—	0.82	0.584^f	4.1	[10]

^{a}) ROSAT PSPC count rate; ^{b}) Ages for pulsars are estimated as $P/(2\dot{P})$,
for RX J1856 the estimate of its age comes from kinematical considerations.
^{c}) Distance to PSR B1055-52 is uncertain ($\sim$ 0.9-1.5 kpc)
^{d}) Total count rate (blackbody + non-thermal)
^{e}) Distances determined through parallactic measurements
^{f}) Distances determined with dispersion measure
[1] Treves et al. (2000) ; [2] Kaplan et al. (2002); [3] Zane et al. (2002);
[4] Hambaryan et al. (2001); [5] Haberl, Zavlin (2002); [6] Zampieri et al. (2001);
[7] Becker, Trumper (1997); [8] Mirabal, Halpern (2001); [9] Pavlov et al. 2001;
[10] ATNF Pulsar Catalogue (see Hobbs et al. 2003); [11] Haberl et al. (2004, in prep.)

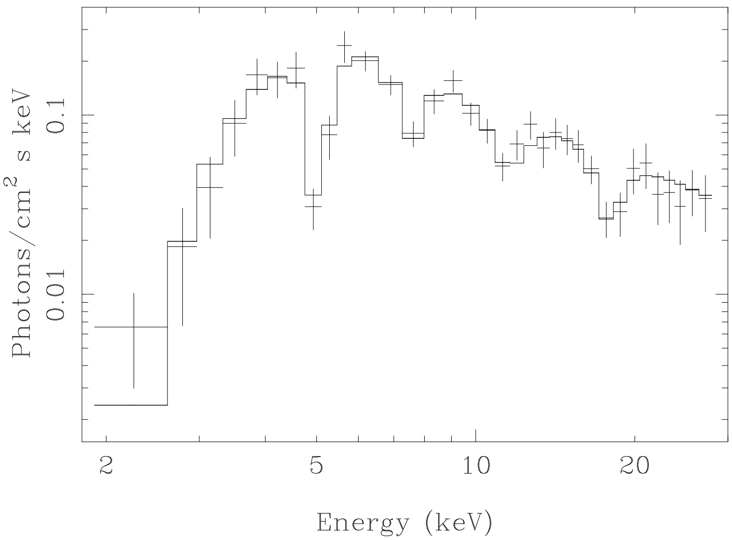

Figure 2. Spectrum of SGR 1806-20. Observed by RXTE. From Ibrahim et al. (2002).

Observations

1. Magnetic field determination from cyclotron features

- SGR 1806-20. $B \sim 10^{15}$ G (if it is a proton cyclotron resonance feature) (Ibrahim et al. 2002). See fig. 2.
- AXP 1RXS J170849-400910. $B \sim 9 \cdot 10^{11}$ G (electron resonance) or $1.6 \cdot 10^{15}$ G (proton resonance) (Rea et al. 2003).
- AXP 1E 1048-5937. $B \sim 1.2 \cdot 10^{12}$ G (electron resonance) or $B \sim 2.4 \cdot 10^{15}$ G (proton resonance) (Gavriil et al. 2002, 2003). Not a very strong feature. Not consistent with spin-down.
- 1E 1207.4-5209. CCO in SNR. $B \sim 8 \cdot 10^{10}$ G (electron resonance) or $\sim 1.6 \cdot 10^{14}$ G (proton resonance) (Bignami et al. 2003). From spin-down measurements the field estimate is $B \sim (2-3) \cdot 10^{13}$ G (see fig. 3).
- RBS 1223. "Magnificent seven". $B \sim (2{-}6) \cdot 10^{13}$ G (proton resonance) (Haberl et al. 2003).

2. Relations between AXPs and SGRs

Observations of X-ray bursts from AXPs which are very similar to the ones from SGRs.

- AXP 1E1048-5937 (Gavriil et al. 2002, 2003). See fig. 4.

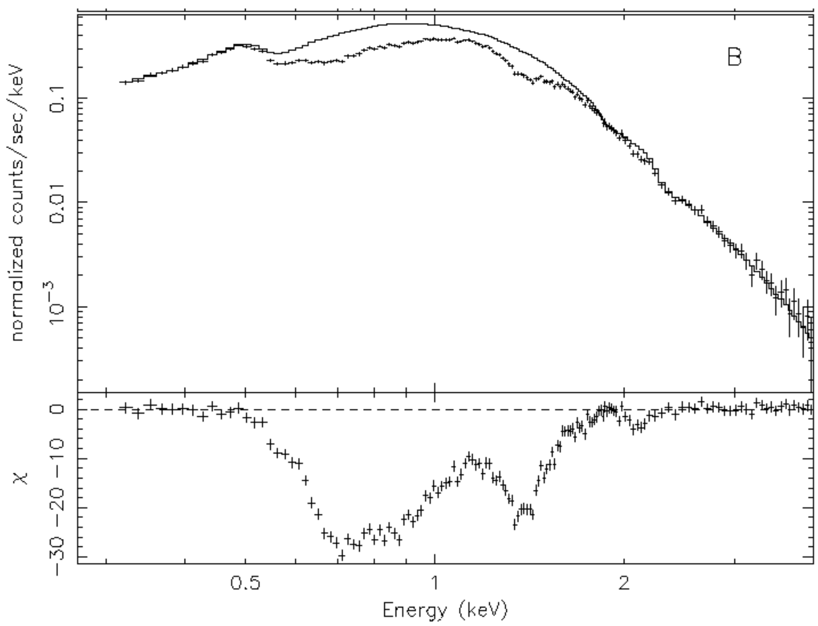

Figure 3. Spectrum of 1E 1207.4-5209 collected by the MOS camera on the EPIC instrument of XMM-Newton. Also the best fit continuum and residuals are shown. From Bignami et al. (2003).

- AXP 1E 2259+586 (Kaspi, Gavriil 2002).

3. More radiopulsars.

- On-line ATNF catalogue. 1300 PSRs (Hobbs et al. 2003).
- Parkes survey. > 800 new PSRs (Kramer et al. 2003, Morris et al. 2002).
- Pulsar with magnetar parameters: $p = 6.7$ s, $B \approx 9.4{\cdot}10^{13}$ G (McLaughlin et al. 2003).
- A new double NS system (Burgay et al. 2003).

4. NS initial velocity distribution

- New PSRs proper motions (Brisken et al. 2003).
- New model for the galactic distribution of free electrons (Cordes, Lazio 2002).

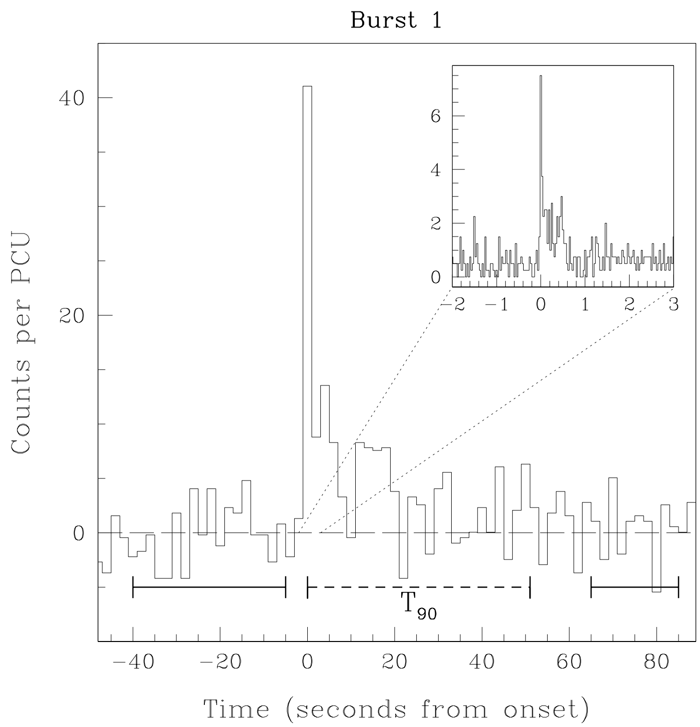

Figure 4. AXP 1E 1048-5937 burst. Observed by RXTE. From Gavriil et al. (2002).

- Bimodal initial velocity distribution with two maxwellian components: σ_1=90 km s^{-1} and σ_2=500 km s^{-1} (Arzoumanian et al. 2002).

5. Proper motions of radioquiet INSs

- RX 1856.5-3754. $d = 117$ pc, $v_T = 185$ km s^{-1}. Excludes accretion from the ISM (Walter, Lattimer 2002; Kaplan et al. 2002). Distance to this source is still uncertain.

- RX 0720.4-3125. $v_T = 50(d/100\text{pc})$ km s^{-1}. Excludes accretion from the ISM (Motch et al. 2003).

6. Discovery of a new Geminga-like object

- 3EG 1835+5918. EGRET source (Halpern et al. 2002).

7. $\dot{p}$ for radioquiet INS.

- RX 0720.4-3125. $\dot{p} \sim (3-6)\cdot 10^{-14}$ (Zane et al. 2002).

- Kes 75. $p = 0.325$ s, $\dot{p} = 7.1\cdot 10^{-12}$ (Mereghetti et al. 2002).

- G296.5+10. $p = 0.424$ s, $\dot{p} = (0.7 - 3) \cdot 10^{-14}$ (Pavlov et al. 2002).
- Non-constant $\dot{p}$ for 1E 1207.d-5209 (Zavlin et al. 2003).

8. IR radiation from AXPs

- 1E 2259+586 (Hulleman et al. 2001).
- 1E 1048.1-5937 (Wang, Chakrabarty 2002).
Variability (Israel et al. 2002).
- 1RXS J1708.9-400910 (Israel et al. 2003).

9. Pulsars jets and toruses

- Variable jet of the Vela pulsar (Pavlov et al. 2003)
- Alignment between spin axis and spatial velocity for Crab and Vela pulsars (see for example Lai et al. 2001)

10. NS masses

- Vela X-1. $M \approx 2\,M_{\odot}$ (Quaintrell et al. 2003).
- PSR J0751+1807. $M \approx 1.6 - 1.28\,M_{\odot}$ (Nice, Splaver 2003).

11. Gravitationaly redshifted line from an accreting NS

- EXO 0748-676. z=0.35 (Cottam et al. 2002).

Theory

1. Spectra of strongly magnetized NSs

- Lines for high magnetic field (Zane et al. 2001; Ho, Lai 2001, 2003; Ozel 2001).
- Bare neutron and quark star emission (Turolla et al. 2004).
- Atmospheres and opacities for high magnetic fields (Potekhin, Chabrier et al.).

2. Gould Belt in population synthesis calculations

- Population synthesis of EGRET sources (Grenier 2003).
- Population synthesis of young cooling INS (Popov et al. 2003a).

3. SN explosions (see the contribution by Stephan Rosswog in this volume for more details)

- 3-Dimensional core-collapse (Fryer, Warren 2003).
- Nucleosynthesis, collapse dynamics (Woosley et al. 2002).
- Jets, GRB connection, X-ray flashes, HETE-2 data (Lamb et al. 2003).

4. Accretion and spin evolution

- CDAF – convection dominated accretion flows (Igumenschev et al. 2002, 2003)
- Low angular momentum accretion (Proga, Begelman 2003).
- Accretion onto INSs (Toropina et al., Romanova et al. 2003).
- Propeller regime for INSs (Ikhsanov 2003).

5. Cooling curves

- Impact of superfluidity on cooling (Kaminker et al. 2003, Tsuruta et al. 2002).
- Cooling curves for quark stars (see contributions by Grigorian et al. and others in this procedings)

6. Discussion on models of fossil discs around INSs

- Discs can explain AXPs and other types of INS (Alpar 2003).
- Discs can't explain it (Francischelli, Wijers 2002).
- General picture of pulsars with jets and disks (Blackman, Perna 2003).

7. Electrodynamics of magnetars

- SGR phenomena due to magnetospheric activity (Thompson et al. 2002).

2. Discussion

Here we discuss some results in more details focusing on topics of our personal interest.

Spectral features and magnetic field determination

Investigations on the emission properties of INSs started quite a long time ago, mainly in connection with the X-ray appearance of PSRs. In the '70s it was common wisdom that the radiation emitted by INSs come directly from their solid crust and is very close to a blackbody. Lenzen and Trumper (1978)

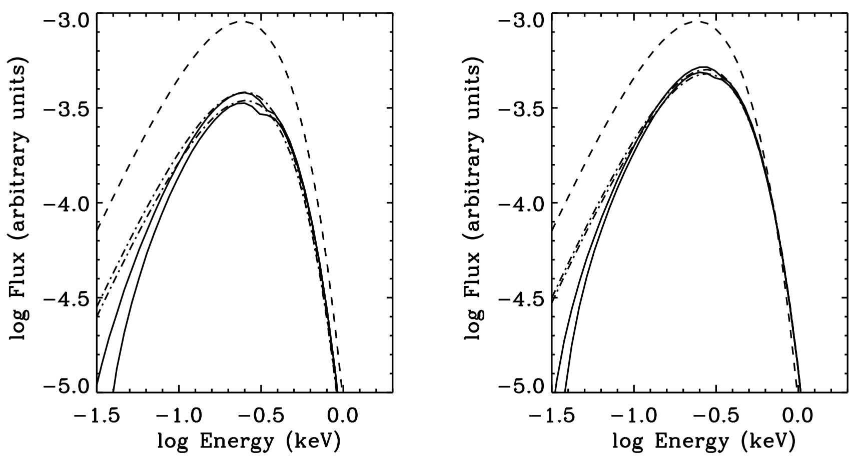

Figure 5. Model spectra of a naked neutron star. The emitted spectrum with electron-phonon damping accounted for and $T_{surf} = 10^6$ K. Left panel: uniform surface temperature; right panel: meridional temperature variation. The dashed line is the blackbody at T_{surf} and the dash-dotted line the blackbody which best-fits the calculated spectrum in the 0.1–2 keV range. The two models shown in each panel are computed for a dipole field $B_p = 5 \times 10^{13}$ G (upper solid curve) and $B_p = 3 \times 10^{13}$ G (lower solid curve). Spectra are at the star surface and no red-shift correction has been applied. From Turolla, Zane and Drake (2004).

and Brinkmann (1980) were the first to address in detail the issue of the spectral distribution of INS surface emission. Their main result was that the star emissivity is strongly suppressed below the electron plasma frequency which, for the case of X-ray pulsars, is at about 1 keV.

Later on the role played by the thin atmosphere covering the star crust in shaping the emergent spectrum started to be appreciated. Romani (1987) investigated the properties of fully-ionized, H atmospheres around unmagnetized, cooling NSs and showed that the spectrum is harder than a blackbody at the star effective temperature. Spectra from magnetized NSs were studied, under similar hypotheses, by the St. Petersburg group in a series of papers (Shibanov et. al 1992; Pavlov et al. 1994; Zavlin et al. 1995). Because the opacity is higher in the presence of a strong magnetic field ($B \sim 10^{12}$ G or larger), magnetic spectra tend to be more blackbody-like. In these investigations, the focus was on middle-aged NSs with $T_{eff} \approx 10^5 - 10^6$ K and typical fields $\approx 10^{12}$–10^{13} G. Under such conditions the bulk of the emission is the soft X-ray band (≈ 0.1–1 keV) while the electron cyclotron line at $\hbar\omega_{c,e} \sim 11.6(B/10^{12}\ \mathrm{G})$ keV falls in the tens of keVs range. For this reason no detailed modeling of the line was attempted. An (approximated) treatment of the proton cyclotron line was

included, although its energy, $\hbar\omega_{c,p} \sim 6.3(B/10^{12}\,\mathrm{G})$ eV, falls in the optical/UV region for pulsar-like fields. Being related to a resonant behaviour of the opacity for the extraordinary mode, the proton cyclotron line appears as an absorption feature in the spectrum. Atmospheres comprised of heavy elements (Fe) were studied by Rajagopal et al. (1997); the emergent spectra exhibit a variety of emission/absorption features produced by atomic transitions. Such models, however, suffer from our lack of knowledge on ionization state and opacities of metals in a strong magnetic field.

Until quite recently, model atmosphere calculations were restricted to fields not exceeding a few 10^{13} G. Ultra-magnetized NSs has been long suspected to exist in SGRs. It was only in the late '90s that the positive detection of large spin-down rates in SGR 1806-20 and SGR 1900+14 (Kouveliotou et al. 1998; 1999) provided decisive evidence in favor of the magnetar scenario. At about the same time spin-down measures supported the magnetar nature of the AXPs. In nearly all AXPs and in at least in one SGR, a thermal component was clearly detected in the X-ray spectrum. This prompted renewed interest in the study of the thermal emission from NSs with surface fields in the 10^{14}–10^{15} G range. The main goal was to identify possible signatures of the super-strong magnetic field which could provide an unambiguous proof of the existence of magnetars. The proton cyclotron resonance, being in the keV range for a magnetar, is an ideal candidate for this. Zane et al. (2001) were the first to construct model atmospheres for $B \sim 10^{14}$–10^{15} G and luminosities appropriate to SGRs/AXPs. They considered completely ionized, pure H atmospheres in radiative equilibrium and solved the transfer problem in a magnetized medium in the normal modes approximation and planar symmetry. Computed spectra are blackbody-like and show a relatively broad absorption line at $\hbar\omega_{c,p}$ with an equivalent width $\mathrm{EW} \approx 100$ eV, within the detection capabilities of Chandra and XMM-Newton. This issue was further addressed by Ho and Lai in a recent series of papers (Ho, Lai 2001, 2002; Lai, Ho 2003). Their approach differs from that used by Zane et al. (2001) in the treatment of vacuum polarization and mode conversion. This affects the line properties in a non-negligible way. In the first paper no adiabatic mode conversion was included and the line EW they found is larger than that predicted by Zane et al. Accounting for adiabatic mode conversion produces a depression in the continuum at energies close to the cyclotron energy, thus reducing the line EW to values somewhat smaller than those of Zane et al. Spectra from ultra-magnetized NSs were also computed by Ozel (2001) who, however, did not account for the proton contributions.

While a proper solution of transfer problem in media at $B \gg B_{QED} \simeq 4.4 \times 10^{13}$ G has necessary to wait for a description in terms of the Stokes parameters, the search for the proton cyclotron feature in the spectra of AXPs and SGRs begun. Up to now no evidence for the proton line has been found in the thermal components of SGRs and AXPs, although these observations can

not be regarded as conclusive yet. Quite recently a cyclotron absorption feature in the spectrum of SGR 1806-20 in outburst has been reported by Ibrahim et al. (2002) and further confirmed by the same group in several other events from the same source (Ibrahim et al. 2003). The line parameters are similar to those predicted by Zane et al. (2001), even if the line in this case is not superimposed to a thermal continuum and is not expected to originate from the star cooling surface. The line energy ($\simeq 5$ keV) implies a field strength $B \sim 10^{15}$ G in excellent agreement with the spin-down measure.

Model spectra from standard cooling NSs proved successful in fitting X-ray data for a number of sources and in some cases solved the apparent discrepancy between the star age as derived from the temperature and from the $\dot{P}/2P$ measure. However, model atmospheres seem to be of no avail in interpreting the multiwavelength spectral energy distribution (SED) of the seven ROSAT INSs. The X-ray spectrum of the most luminous source RX J1856.5-3754 is convincingly featureless and shows, possibly, only slight broadband deviations from a blackbody (Drake et al. 2002; Burwitz et al. 2003). The situation is more uncertain for the fainter sources, and the possible presence of a (phase-dependent) broad feature at 200–300 eV has been reported very recently in RBS 1223 (Haberl et al. 2003). In all the cases in which an optical counterpart has been identified, the optical flux lies a factor $\approx 5 - 10$ above the Rayleigh-Jeans tail of the blackbody which best-fits the X-rays (Kaplan et al. 2003).

The small radiation radius implied by the distance (~ 120 pc, but this value is still under debate) led to the suggestion that RX J1856.5-3754 may host a quark star (Drake et al. 2002; Xu 2002, 2003). Other, more conventional explanations are well possible. Pons et al. (2002) and Braje and Romani (2002) suggested a scenario in which the X-rays come from a hotter region close to the poles, while the reminder of the star surface is at lower temperature and produces the optical/UV flux. While this picture is appealing and still consistent with the lack of pulsations (pulsed fraction $< 1.3\%$ see Haberl et al. 2003), no explanation is offered for the formation of a pure blackbody spectrum in an object which should conceivably be covered by an optically thick atmosphere. Very recently Turolla et al. (2004) considered the possibility that RX J1856.5-3754 is a bare NS, that is to say no atmosphere sits on the top of its crust. Lai and Salpeter (1997; see also Lai 2000) have shown that for low surface temperatures and high enough magnetic fields, the gas in the atmosphere undergoes a phase transition which turns it into a solid. While the onset of such a transition appears unlikely for an H atmosphere, it might be possible for a Fe composition for the temperature of RX J1856.5-3754 ($T_{BB} \sim 60$ eV) and $B > 3 - 5 \times 10^{13}$ G. Turolla et al. computed the spectrum emitted by the bare Fe surface including electron-phonon damping in the highly degenerate crust, and found that it is close to depressed blackbody. If indeed RX J1856.5-

3754 is bare NS, and keeping in mind that their results depend on the assumed properties of the crust-vacuum interface, the optical/UV emission may be due to a thin H layer which cover the star and is optically thick up to energies $\approx 10 - 100$ eV. The Rayleigh-Jeans optical/UV emission is at the star surface temperature, and the optical excess with respect to the X-ray spectrum arises because the latter is depressed.

Velocity distribution

The number of PSRs with known transverse velocities is continuously growing. New velocity determinations are based on a new model of galactic distribution of free electrons (Cordes, Lazio 2002). Unlike situation 10 years ago, when updated data on free electrons distribution leaded to nearly doubling of distances (and, correspondently, transverse velocities), results of Cordes and Lazio brought serious corrections only for distant PSRs.

In last two years a new initial velocity distribution of NSs became standard. It is a bimodal distribution with peaks at ~ 130 km s^{-1} and ~ 710 km s^{-1} (Arzoumanian et al. 2002). Contribution of low and high velocity populations is nearly equal. Brisken et al. (2003) confirm this type of distribution, however they give arguments for smaller fraction of low velocity NSs (about 20%).

The nature of this bimodality is unknown, and recently several papers appeared where authors suggested (or modified) different kick mechanisms. There are three main mechanism for a natal kick (see for example Lai et al. 2001). The first is a hydrodynamical one. In many models of that mechanism NSs do not recieve kicks higher than $\sim (100 - 200)$ km s^{-1} due to it (Burrows et al. 2003). The second one is a modification of an electromagnetic rocket mechanism (see Huang et al. 2003). In this scenario velocity is dependent on the initial spin rate ($v \propto p^{-2}$). It can provide high velocities if the initial spin period of a NS is about 1 ms (probably quark stars can spin faster than NSs, so for them this mechanism can be more effective). The third mechanism is connected with instabilities in a newborn NS which lead to it fragmentation into two stars followed by an explosion of the lightest one (see Colpi, Wasserman 2002). Also one should have in mind disruption of high-mass binaries, so that a newformed compact objects recieve significant spatial velocity due to orbital motion even without any natal kick (Iben, Tutukov 1996). However, this mechanism can not provide enough number of high velocity NSs to explain the second peak of the distribution.

In connection with quark stars one can speculate, that additional energy due to deconfinement can lead to additional kick, so among high velocity compact objects the fraction of quark stars can be higher. For example, if the delayed deconfinement proposed by Berezhiani et al. (2003) is operating (see the contribution by Bombaci in this proceedings), then quark stars can obtain additional

(second) kick. Note, that two the most studied NSs – Crab and Vela (which both show spin-velocity alignment, glitches and other particular properties) – belong to low velocity population. Also most of compact objects in binaries in the scenario with delayed deconfinement should belong to low velocity normal NSs as far as otherwise there is a high probability of system disruption.

Young close-by NSs and the Gould Belt

The Gould Belt is a structure consisting of clusters of massive stars. The Sun is situated not far from the center of that disc-like structure. The Gould Belt radius is about 300 pc. It is inclined at 18° respect to the galactic plane.

Due to the presence of the Belt the rate of SN around us (say in few hundred parsecs) during last several tens of million years is higher, than it is in an average place at a solar distance from the galactic center. Because of that there should be a local overabundance of young NSs which can appear as hot cooling objects, as gamma-ray sources etc.

Grenier (2003) estimated a number of possible unidentified EGRET sources originated from the Belt. We (Popov et al. 2003a) calculated Log N – Log S distribution of cooling NSs in the solar vicinity, which can be observed by ROSAT and other X-ray missions. Results are shown in the fig. 6.

Period evolution of INSs and accretion from the ISM

In early 70s it was suggested that INSs can be observed due to accretion of the ISM and that significant part of INSs is at that stage. Actually, for such a prediction it is necessary to make some assumptions about magnetorotational evolution of NSs. In particular, that a combination of spin period, magnetic field, spatial velocity and density of the medium is such that accretion is possible and proceeds at nearly Bondi rate. Recent data shows that these assumptions were incorrect. ROSAT observations resulted in just a few radioquiet INSs non of which is considered to be a good candidate to be an accreting INSs. There are many reasons for that (see Popov et al. 2003b for discussion).

Recent studies show that it is very difficult for an INS to reach the stage of accretion. There are three main reasons for that:
i). High spatial velocity.
ii). Magnetic field decay.
iii). Long subsonic propeller stage.

Subsonic propeller stage was introduced by Davies and Pringle (1981). Recently Ikhsanov (2003) re-investigated this issue in connection with INSs. His main conclusion is that in a realistic situation an INS spends a significant part of its life ($> 10^9$ yrs) in this stage during which only a small amount of matter can diffuse inwards and reach the star surface. If this situation is realized in nature than even many of low-velocity INSs may never become bright ac-

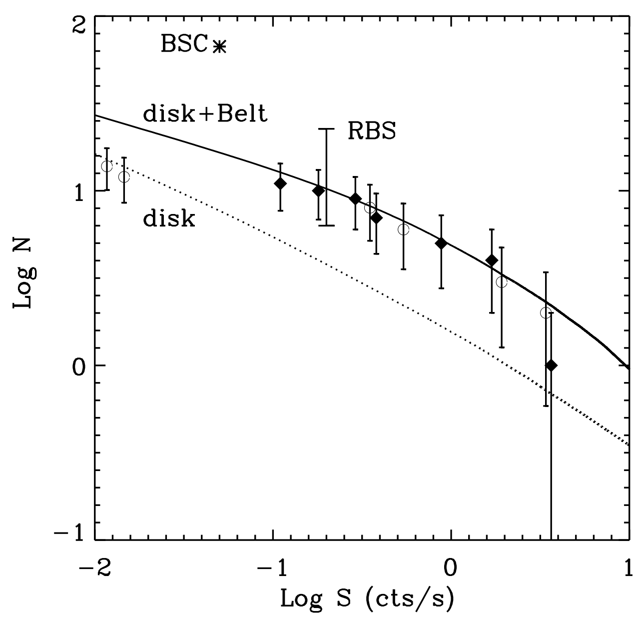

Figure 6. Log N – Log S distribution for close-by cooling INSs. Black symbols are plotted if the dimmest source at specified flux is one of the "Magnificent seven". Otherwise we plot an opaque symbol (see the list of sources in table 1). Two lines represent results of calculation. Dotted line — only stars from the galactic disc contribute to the Log N – Log S distribution. Solid line — contribution of the Gould Belt is added. "RBS" and "BSC" are two observational limits, obtained from the ROSAT data (RBS: Schwope et al. 1999; BSC: Rutledge et al. 2003). From Popov et al. (2003a).

cretors. Long subsonic propeller stage also leads to very long spin periods of INSs at the onset of accretion, much longer, than it was suggested for example in Prokhorov et al. (2002), who explored period evolution of INSs in some details.

Even if an INS starts to accrete, than its luminosity can be very low due to:
i). Heating.
ii). Magnetospheric effects.
iii). Low accretion rate due to turbulence etc.

Heating was discussed in detailes by Blaes et al. (1995). During the last two years last two topics attracted much interest. Magnetospheric effects were studied in a serie of papers by Romanova, Toropina et al. 2D MHD simulations have shown that accretion onto a rotating dipole is substantially different from that onto an unmagnetized star (Romanova et al. 2003; Toropina et al. 2003)

Magnetic effects scales with the magnetic field strength. For lower field they are less pronounced.

Recent investigations strongly support the idea that the Bondi rate is just an upper limit which is rarely realized in nature (see Popov et al. 2003b and references therein). 2D and 3D simulations of accretion flows show that convection and other effects can reduce the accretion rate by orders of magnitude. In particular Igumenshchev et al. (2002, 2003) explored so-called convection dominated acretion flows (CDAF). Proga and Begelman (2003) stidied accretion with low angular momentum. Both studies were done for black hole accretion and showed very low accretion efficiency. However, these results in principle can be applied to isolated NSs (see Perna et al. 2003).

According to all these studies there is not much hope to observe accreting INSs.

3. Conclusion. What do we – astrophysicists – want from QCD theorists & Co.?

Astronomy is in some sence a unique science: we have only emission from objects under investigation. Because of that there is a wide field for speculations. Having a lot of uncertain parameters to explain properties of observed compact objects we have troubles even without quark stars!

What do we want to have from theoretical physicists as an input for astrophysical models of compact objects to produce some output comparable with observations. We want initial parameters of quark stars + evolutionary laws:

- Initial spin period, magnetic field, spatial velocity, mass, radius etc. (plus possible correlations between them).
- "Ejectorability" (ability to produce relativistic wind, i.e. to produce a radio pulsar).
- Emission properties of the surface of bare strange stars.
- Cooling curves.
- Magnetic field decay.

We hope that this brief review will help to link advanced theoretical research in physics of extremely dense matter with observational properties of compact objects.

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